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AN OBSERVATION OF THE (0,0) NEGATIVE BAND OF N_2^+ IN THE DAYGLOW

by E. C. Zipf, Jr., and W. G. Fastie

Prepared under Grant No. NsG-193-62 *by*
JOHNS HOPKINS UNIVERSITY
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On May 7, 1963, at 1611 EST, an Aerobee Hi rocket was launched from Wallops Island, Virginia, carrying photometers that measured dayglow emission at 3914A, 6300A and 6325A in the E and F_1 regions of the ionosphere. This paper discusses the blue (3914A) photometer experiment. The red-photometer measurements have been published in a separate report (Zipf and Fastie, 1963).

The blue photometer consisted of an Ascop type 541A photomultiplier tube, an interference filter, blocking filter and a baffle that minimized the effects of solar light scattered off the instrument. The composite filter had a bandpass of 42A with a maximum transmission of 25% at 3914A. The instrument was calibrated absolutely by measuring its response to a monochromatic source of known brightness. The photometer had an acceptance angle of 3.85×10^{-3} steradians. All observations were made in the direction of the rocket axis at an angle of elevation that varied from 87 to 73 degrees. The rocket yawed with a period of 49 seconds.

In Figure 1 the total zenith intensity of the day airglow at 3914A has been plotted as a function of altitude. The open circles represent intensity measurements made as the rocket climbed to peak altitude, while the solid points were obtained during descent. The data have been corrected for modulation effects due to the yaw of the rocket.

At 100 km the dayglow emission at 3914A had a total zenith intensity of 6.7 kr (kilorayleighs) with an experimental uncertainty of about 20%. Recent observations by Wallace (private communication)

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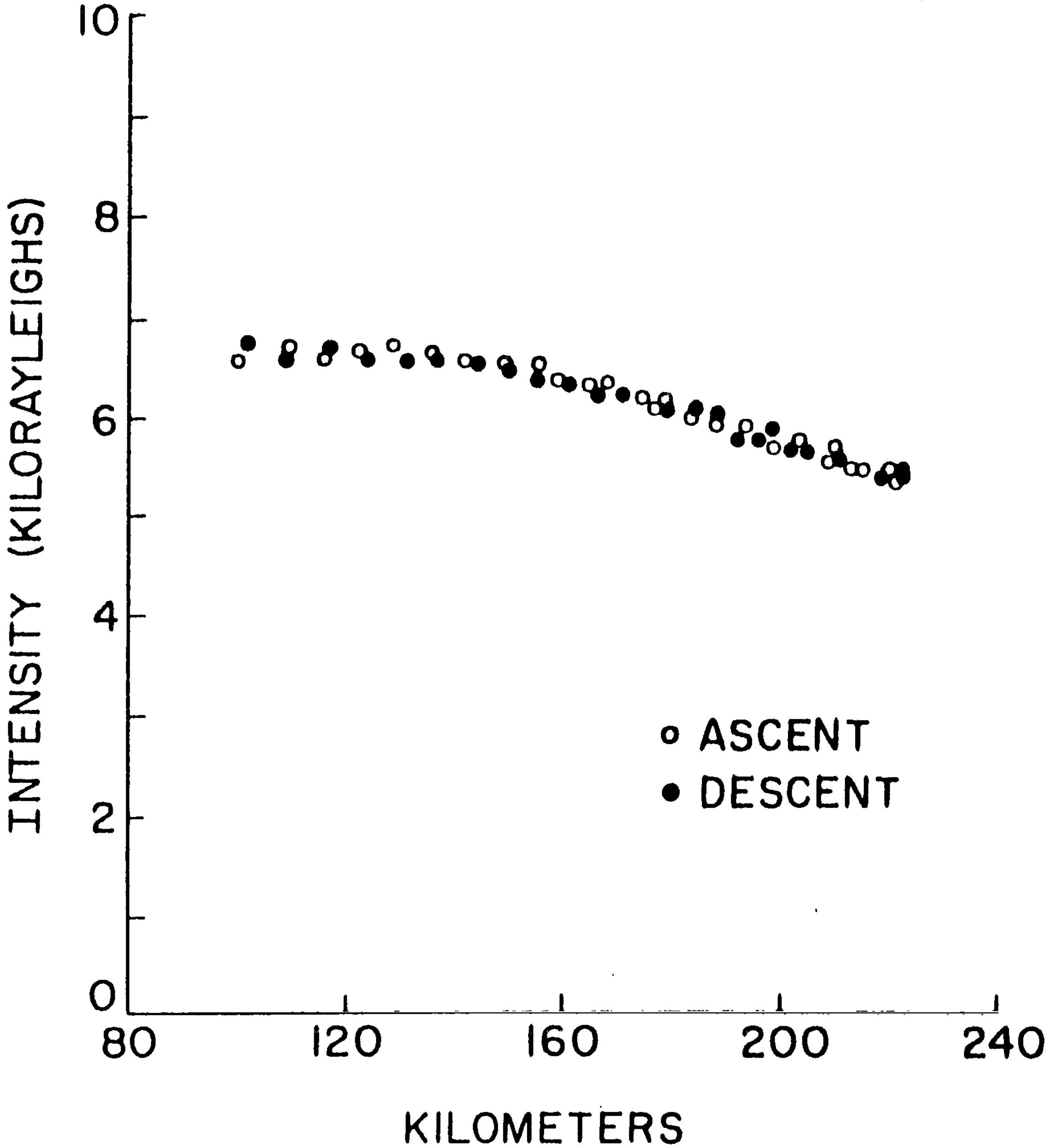

Fig. 1. The total Zenith Intensity of the Day Airglow at 3914A plotted versus altitude.

who observed the negative bands of N_2^+ in the dayglow with a scanning monochromator, support the assumption that the radiation detected by our (3914A) photometer is due to the (0, 0) negative band of N_2^+. From 100 to 130 km the total zenith intensity at 3914A remained nearly constant. But above 130 km the intensity decreased slowly with increasing altitude. At the peak altitude (223 km) the total zenith intensity was about 5.4 kr indicating that the majority of excited N_2^+ ions were located at still higher altitudes in the F_2 region.

A smooth curve was fitted to the data of Figure 1 by means of a power series. The emission rate per unit volume for the (0, 0) negative band was then computed as a function of altitude by differentiating this curve. The results are given in Table 1. From these data we have calculated the density of N_2^+ ions in the region from 140 to 223 km on the assumption that resonance scattering of solar light by pre-existing N_2^+ ions is responsible for the excitation of the negative bands. A yield of 0.068 quanta sec^{-1} ion^{-1} (Lytle and Hunten, 1960) was used for this process. These results are included in Table 1 along with values for the electron density which were obtained from an analysis of the ionosonde data taken during the flight.*

Table 1. Density Data from 140 to 220 km.

z (km)	φ [a] (photons $cm^{-3}sec^{-1}$)	$n(N_2^+)$ (ions cm^{-3})	n(e) (e^- cm^{-3})
140	68.6	1.01×10^3	1.7×10^5
150	98.6	1.45	1.9
160	122	1.80	1.95
170	143	2.10	2.0
180	163	2.40	2.3
190	179	2.63	2.8
200	193	2.84	3.4
210	206	3.03	3.9
220	218	3.21	4.3

a. Dayglow emission rate per unit volume at 3914A.

* We are indebted to Mr. Lloyd Lohr, Wallops Island Station, for providing the ionosonde data for the rocket experiment.

Earlier measurements of the density of atmospheric ions from 100 to 200 km (Johnson, Meadows and Holmes, 1958) indicated that N_2^+ was a minor constituent in the ionosphere with a density of less than 3×10^3 ions cm^{-3}. Our results are in agreement with their findings. The maximum N_2^+ density inferred from our photometer data was 3.21×10^3 ions cm^{-3} at 220 km; this amounts to only 0.75% of the total positive ion concentration at that altitude. At lower altitudes in the E region the density of N_2^+ ions is much smaller and our data indicates that below 125 km $n(N_2^+) < 4 \times 10^2$ ions cm^{-3}. The number of N_2^+ ions above 220 km was approximately 8.0×10^{10} ions cm^{-2}. It is interesting to note that while the majority of N_2^+ ions are located in the F_2 region, they reach their maximum density relative to the other atmospheric ions (1.1%) near 180 km in the F_1 region.

Photoionization of molecular nitrogen by solar EUV radiation is the chief daytime source of N_2^+ in the E and F regions of the ionosphere. The principal loss mechanisms include dissociative recombination, charge exchange and ion-atom interchange with the atmospheric gases. In the quasi-steady state, the density of N_2^+ ions, $n(N_2^+)$, is given by

$$n(N_2^+) \quad = \quad Q \,/ (\alpha\, n(e) \quad + \quad \gamma_1 n(O) \quad + \quad \gamma_2 n(O_2)) \qquad (1)$$

where Q is the photoionization rate,

α is the dissociative recombination coefficient, and

γ_i is the total rate of coefficient for the destruction of N_2^+ ions in interactions with atomic oxygen (i = 1) or with molecular oxygen (i = 2). The electron, atomic oxygen and molecular oxygen densities are represented by $n(e)$, $n(O)$ and $n(O_2)$ respectively.

Kasner, Rogers and Biondi (1961) found from microwave measurements on low-energy nitrogen plasmas that $\alpha(N_2^+) = (2.8 \pm 0.5) \times 10^{-7}$ cm^3 sec^{-1} at 300^0 K. No detailed information on the temperature dependence of $\alpha(N_2^+)$ is available from laboratory studies. However, from an analysis of ion-composition data in the E and F_1 regions Norton, VanZandt and Denison (1962) concluded that $\alpha(N_2^+)$ varies as $1/T(^0K)$. We have assumed this temperature dependence in calculating the loss rate due to dissociative recombination.

The ion-molecule reaction

$$N_2^+ \quad + \quad O_2 \xrightarrow{k_1} NO^+ \quad + \quad NO \tag{2}$$

has been investigated by Galli, Giardini-Guidoni, and Volpi (1963) who concluded from their mass spectrometer studies that $k_1 \leq 2.1 \times 10^{-13}$ cm^3 sec^{-1}. Fite and his co-workers (1962) studied the reaction

$$N_2^+ \quad + \quad O_2 \xrightarrow{k_2} O_2^+ \quad + \quad N_2 \tag{3}$$

and reported that $k_2 \sim 2 \times 10^{-10}$ cm^3 sec^{-1}. In the E region where $n(O_2) \sim 5 \times 10^{11}$ cm^{-3}, reaction (3) is an important loss mechanism for N_2^+.

We have calculated the photoionization rate, Q, with the sun at an altitude of 30.5 degrees using the model atmosphere proposed by Norton, VanZandt and Denison (1962). The absorption and photoionization cross sections tabulated in their paper were used in these computations. Values for the photoionization rate for N_2^+ at altitudes from 140 to 220 km are given in Table 2. The total loss frequency, $Q/n(N_2^+)$, was derived from these results and the experimental values for $n(N_2^+)$.

Table 2. Photoionization Rates and Loss Frequencies for N_2^+ from 140 to 220 km.

z	$(Q)^a$	$(Q/n(N_2^+))^b$	$(\alpha n(e))^c$
(km)	(ions $cm^{-3}sec^{-1}$)	(sec^{-1})	(sec^{-1})
140	1.65×10^3	1.63	0.030
150	1.37	0.946	0.026
160	1.03	0.572	0.023
170	0.753	0.358	0.020
180	0.552	0.230	0.021
190	0.407	0.155	0.024
200	0.304	0.107	0.026
210	0.230	0.076	0.028
220	0.176	0.055	0.030

a. Photoionization rate for the production of N_2^+ by solar EUV radiation.
b. Total loss frequency.
c. Loss frequency due to dissociative recombination.

In several current theories of the E and F regions dissociative recombination is regarded as the dominant loss mechanism for N_2^+. While this is probably so in the F_2 region, it is clearly not the case at altitudes below 180 km. This may be shown by comparing the total loss frequency at a given altitude with the corresponding recombination frequency listed in Table 2. At 160 km, for example, less than 5% of the N_2^+ ions are destroyed by dissociative recombination. Similar calculations with the model atmospheres proposed by Bates and Patterson (1961) and by Watanabe and Hinteregger (1962) also support the conclusion that dissociative recombination is a minor loss process for N_2^+ below 180 km. Hunten (1963) reached a similar conclusion from his studies on sunlit auroras.

Approximate values for the rate coefficients γ_1 and γ_2 were obtained by fitting the experimental data with equation (1). The photoionization rates, Q, given in Table 2 and the densities, n(O) and n(O_2), from Norton et al (1962) were used in this calculation. Below 180 km the computed N_2^+ densities were in satisfactory agreement with the experimental results with $\gamma_1 = 2.1 \times 10^{-11}$ cm^3 sec^{-1} and $\gamma_2 = 2.2 \times 10^{-10}$ cm^3 sec^{-1}. The agreement between γ_2 and k_2 shows that one of the principal loss processes for N_2^+ in the E and F_1 regions is charge exchange with O_2. Reactions with atomic oxygen are also important. Here again charge exchange

$$N_2^+ \quad + \quad O \longrightarrow O^+ \quad + \quad N_2 \qquad (4)$$

seems to be the most likely process. The value for γ_1 is sufficiently large that even at 220 km, where n(O) $\sim 4 \times 10^9$ cm^{-3}, reactions with atomic oxygen compete favorable with dissociative recombination in destroying N_2^+ ions.

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